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NANOTECHNOLOGY: AN EMERGING NEW TECHNOLOGY FOR INDONESIA PART I. NANOTECHNOLOGY IN GENERAL

Ratnawati*), D.D. Anggoro*), G.A. Mansoori**)

Abstract

Nanotechnology is shortly defined as the ability to build micro and macro material and product with atomic precision. Feynman is considered to be the scientist who put a strong foundation for the development of nanotechnology with his phenomenal speech in 1959 entitled "There's Plenty of Room at the Bottom - An invitation to enter a new field of physics." The invention of scanning tunneling microscope, followed by atomic force microscope, has enabled the world to see atoms and molecules, and opened more possibility for the scientists to develop nanotechnology. Other breakthrough in nanotechnology is the discoveries of fullerene, carbon nanotube and diamondoids. Nanotechnology has found various fields of application, such as in biomedical, materials, aerospace, surface science, and energy, to name a few, lead by the United States, Europe, and Japan. The technology brings benefits as well as risks to human life. Some of the risks are potentially global in scope. It is why a single, trustworthy, international administration holding controls on the technologyis is urgently needed.

Keywords : *AFM, carbon nanotube, diamondoid, fullerene, nanotechnology, STM..*

Introduction

In early 1950s, when computers were invented, a room-sized computer was considered to be a sophisticated electronic equipment even though it was infinitely slower than the present day computers. In the middle of 1980s, a pocket-sized or even smaller computer could be made. As the scientists kept on doing research to make everything smaller, they came into one point of view that even a pocket-sized computer was still too big. The microchips inside the computer still hold millions of atoms, and the are still visible to the naked eyes. The technology, including microchips technology, which handles atoms and molecules in bulk is called bulk technology. The new technology, nanotechnology, is any technology which exploits phenomena and structures that occur at the nanometer scale. Nanotechnology deals with atoms and molecules, and handles individual atoms and molecues with control and precision. The most complete definition of nano-technology is given by the US National Science and Technology Council (Roco *et al.*, 2000) as follows: "*The essence of nanotechnology is the ability to work at the molecular level, atom by atom, to create large stuctures with fundamentally new molecular organization. The aim is to exploit these properties by gaining control of structures and devices at atomic, molecular, and supramolecular levels and to learn to efficiently manufacture and use these devices.*" In short, nanotechnology is the ability to build micro and macro material and product with atomic precision [Mansoori, 2005; Mansoori and Soelaiman, 2005].

Nanotechnology and nanoscience research has attracted scientists all over the world during the last two decades. The huge increase in publication of books and journals dedicated to this new technology is the evidence of how important and attractive this technology is. There are, already, at least 12 major journals dedicated to nanotechnology and nanoscience (Curtright *et al.*, 2004). The nanotechnology and nanoscience research covers a wide range of fields, including synthesis and assembly, biological approaches and applications, dispersion and coatings, nanodevices, and consolidated materials, lead the United States, Europe, and Japan (Siegel *et al.*, 1999).

Indonesia, a natural resource-rich country, has already recognized nanotechnology as an important area for research, development and engineering as well as industry. There have been several workshops and other activities organized/funded by the Indonesian Ministry of Research and Technology (Anonimous, 2005) to prepare for some coordinated policy and research programs. The government laboratory, the Research and Development Center for Material Science and Technology (RDCMST), is currently in process of initiating and establishing cooperative program in nanotechnology research. However, there are still countable reports about the development of nanotechnology in Indonesia. It is the aim of this report, to review the development of

*) Chemical Engineering Department Diponegoro University
Jl. Prof. Soedarto, SH Tembalang, Semarang 50239 Indonesia
**) Departments of Chemical and Bioengineering UIC
825 S. Morgan St. Chicago, IL 60607-7000 USA

nanotechnology in the world and the possibility of developing and applying it in Indonesia.

This report is devided into two parts. Nanotechnology in general, including the importance of nanoscale and the history, breaktrhoughs, benefits, and risks of nanotechnology, are discussed in the first part. In the second part, the report will be focused on the discussion of possibility of developing and applying nanotechnology in Indonesia.

Nanoscale

One nanometer is one billionth of a meter (1 nm = 10^{-9} m), and is equivalent to ten Angstroms (Å). It is about 2/10,000 of the diameter of a human hair. The diameter of an atom is between 1 to 5 Å. One cubic nanometer (nm^3) is roughly 20 times the volume of an individual atom (Mansoori and Soelaiman, 2005). The diameter of a fairly complex molecule is around 10 times the diameter of an atom. Drexler (1987) gave a useful mental image to describe how small an atom was. If an atom were of the size of a marble, a fairly complex molecule would be the size of human fist. However, an atom is too small to see with naked eyes. It is about 1/1,000 the size of bacteria, and bacteria are about 1/10,000 the size of mosquitoes. Various size ranges for different nanoscale objects are shown in Figure 1. The smallest objects, which are in the size of less than 1 nm, are ions, atoms, and molecules. These small entities can only be identified using Scanning Tunneling Microscope (STM). In the next range are human-made devices, such as carbon nanotubes, GMR (giant magneto resistive) layers, SET (Single-electron transistor), and Q-dots (Quantum dots) in laser. Scanning Electron Microscope (SEM) is needed to see these molecular-sized devices as well as the DNA molecule in the size of 2.5 nm, which is the largest molecule of living systems. The SEM is also needed to view virus, which is considered to be the smallest living organism. The bigger objects, such as bacteria and red blood cell, can be observed using optical microscope. It is obvious that the smallest human-made devices are in the range of nanometer. Therefore nanoscale is considered as a magical point on the dimensional scale; structures in nanoscale are considered at the borderline of the smallest human-made devices and the largest molecules of living systems.

Basis of Nanotechnology

The properties of all things around us depend on the behavior of their molecules. Air holds neither its shape nor its volume because its molecules move freely, while water holds a rather constant volume as it changes shape because its molecules stick together as they move about. Metals, such as copper and iron, hold their shapes at normal conditions, because their atoms are fixed in regular patterns. The arrangement of atoms and molecules defines the nature of all things. Carbon atoms arranged in one way become precious diamond, while in another arrangement they become non-precious graphite. Our ability to arrange atoms and molecules lies on the foundation of nanotechnology. The ability to control and manipulate nanostructures will make it possible to exploit new physical, biological, and chemical properties of nanoscale systems (Drexler, 1987; Mansoori, 2005).

The fundamentals of nanotechnology lie on the fact that properties (i.e., chemical, electrical, mechanical, and optical) of substances in the size of nanometer range are different from the those of bulk material, as well as those of the smallest elements, atoms and molecules. Atoms and molecules possess totally different behaviors from those of bulk materials. The properties of atoms and molecules are described by quantum mechanics, while those of bulk material are governed by classical mechanics. Between these two distinct domains, the nanometer range is a threshold for the transition of a material's

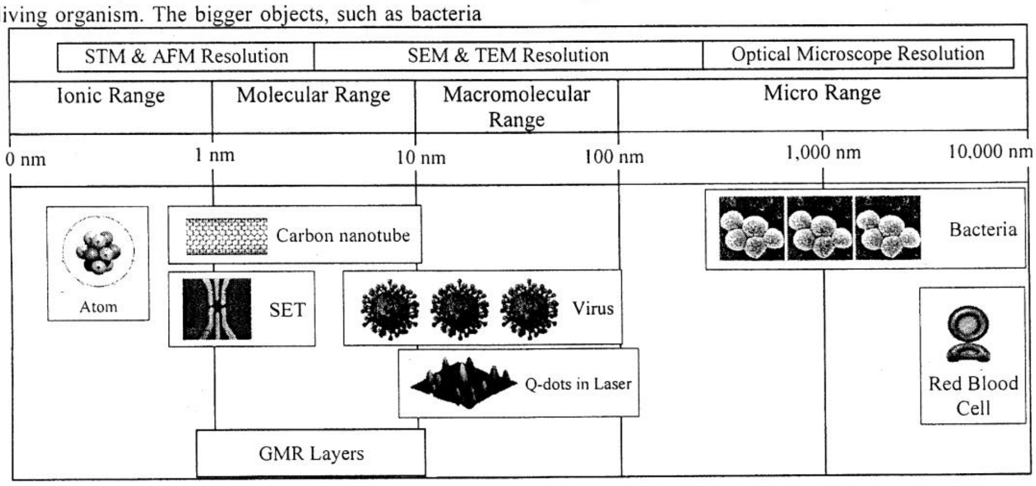

Figure 1. Comparison of size ranges for several entities as compared to several nanotechnology devices [3].

sized materials are intermediate between the properties of the smallest elements and those of the macroscopic materials [Mansoori, 2005; Feynman, 1960).

History of Nanotechnology

The first mention of some of the distinguishing concepts in nanotechnology was in "*There's Plenty of Room at the Bottom - An Invitation to Enter a New Field of Physics*", a lecture given by physicist Richard Feynman, a Nobel prize winner, at an annual meeting of the American Physical Society held in the California Institute of Technology on December 29, 1959 (Feynman, 1960). Feynman looked far beyond the laboratory accomplishment of his time. He emphasized, "*I am not inventing anti-gravity, which is possible someday only if the laws are not what we think. I am telling you what could be done if the laws are what we think; we are not doing it simply because we haven't yet gotten around to it.*" What he intended to talk about was a staggeringly small world that was below, the world of atoms and molecules. Feynman talked about the problem of manipulating and controlling things on a small scale. He described that if various letters were written in code of dots and dashes, if a letter could be represented by six to seven dots and/or dashes, and if one dot or dash required a tiny cube of atoms, each having a volume of 5 Å × 5 Å ×5 Å = 25 $Å^3$, then he had estimated that all of the information in all the books in the world could be written in a cube of material one two-hundredth of an inch wide, which is the smallest piece of dust that can the human eye can see. At the time, it was impossible to see an object in a size of 5 Å wide. It would be only possible if the *electron microscope were 100 times better*. He underlined that it was not impossible nor against the laws of diffraction of the electron. The wave length of the electron in such a microscope was only 1/20 Å, so he certainly believed that the electron microscope could be made much better to view the individual atoms. With the future development of this powerful electron microscope, he added, we could answer all the questions raised in biological fields concerning the sequence of bases in the DNA, the base order in the DNA connected to the order of amino acids in the protein, the structure of the RNA, the organization of the microsomes, how proteins are synthesized, where the RNA goes, etc. We could answer the questions simply by *looking at the thing*. He took the idea of making small machine which did what we wanted from the biological system, the tiny cell of living organism. Miniaturizing computers was another brilliant idea he evoked; the smaller the computers, the faster they could run. He suggested one possibility to make such small device, i.e. by sequences of evaporation and deposition the materials. Another idea he suggested was making the small machine, in which no lubricating problem, to make the devices. He also believed, in his talk, that by having control of the rearrangement the atoms the way we wanted, we would get an enormously greater range of possible properties that substances could have, and of different things that we could do.

In the 1980s Drexler (1987) discussed a future manufacturing technology based on molecular machine systems. He promoted the technological significance of nanoscale phenomena and devices (Drexler *et al.*, 1991). He explained more intensively what was mentioned by Feynman in 1959 about molecular manufacturing inside the very tiny cell of living systems. He explained that *molecular nanotechnology* is thorough, inexpensive control of the structure of matter based on molecule-by-molecule control of products and processes of molecular manufacturing. In macro-scale, industry takes things from nature and transforms them, under various processes, into forms that someone considers useful. Each process is crude, based on cutting, stirring, baking, spraying, grinding, and the like, with lots of waste which is often harmful to environment. On the other hand, there are extremely sophisticated industries of which we are not aware of most of the time, i.e. trees. They neither cut, stir, bake, spray, nor grind to make wood and leaves, instead, they grasp carbon dioxide from the air and take water from the soil, and process them silently with the aid of solar energy using molecular electronic devices, the chloroplasts, resulting a very environmental-friendly *waste*, oxygen. The *molecular machines* of trees are active devices with moving parts of molecular structure, which process carbon dioxide and water into oxygen and cellulose, protein, starch, etc., as *molecular building blocks*. The other molecular machines are used to join these molecular building blocks to form roots, trunks, branches, twigs, solar collectors, and more molecular machinery. They do all this without noise, heat, toxic fumes, or human labor, and they consume pollutants as they go.

Trees give a clue of what molecular nano-technology will be like; producing things using molecular machines which are also able to replicate itself with molecular precision (Drexler *et al.*, 1991). The possibility of making scaleable manufacturing system, which could be made to manufacture a smaller scale replica of itself, was discussed by Feynman in 1983 (Feynman, 1993). The replica would replicate itself in smaller scale, and so on down to molecular scale. The study of man-made self-replicating systems has been taking place more than half a century. The study is focused on the understanding of the fundamentals involved in single-cell biological self-replicating system.

In his 1959 lecture, Feynman talked about assembling atoms to make new molecules: "*The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom. It is not an attempt to violate any laws; it is something, in principle, that can be done; but in practice, it has not been done because we are too big.*" It is common in manufacturing process, to hold, position, and assemble parts in a right way, which is not today possible at the molecular scale. The ability to hold and position parts gives us remarkable flexibility in the manufacturing process. Applying this powerful concept at the molecular scale will require the development of new tools and pose new challenges in many fields (Merkle, 1999).

Mansoori (2005) acknowledged in his book, as most of the nanotechnologists do, that Feynman had put a strong foundation for the development of nanotechnology. For this reason, Mansoori suggested to name the nanometer scale as "the *Feynman* (*ϕ*nman) *scale*", and the notation "ϕ" for the nanometer scale, like Å as used for Angstrom and μ as used for micron scale.

One *Feynman* (ϕ) ≡ 1 nm ≡ 10 Å = 10^{-9} m

Routes of Nanotechnology

Although some of the people did not take Feynman's talk seriously, the Feynman vision has motivated researches on nanotechnology. The development of nanotechnology follows two routes as described implicitly by Feynman, i.e. top-down and bottom-up routes. In top-down route, the focus of the development of nanotechnology is in learning how to build smaller and smaller devices, shrinking manufacturing towards the atomic scale. This route is more readily achievable using the current technology. The computer industry follows this route. In bottom-up route, the focus of the development is in manipulation of individual atoms to build materials atom by atom, molecule by molecule. What the trees do as explained above is an excellent example for bottom-up approach of engineering. Researches in biology, medicine, pharmaceuticals, electronics, energy, and environmental industries, which are rapidly increasing, follow this route.

According to the top-down approach, one of the objectives of nanotechnology is to manufacture smaller and smaller computers with chips in molecular size, while simultaneously keeping the manufacturing costs as low as the manufacturing costs of a piece of wood. According to the bottom-up approach, molecular nanotechnology should let us make inexpensive materials with precisely the desired shape and structured at the molecular scale to optimize material properties. The development of such a capability requires time and resources, including human and natural, just like the other technologies in the development stage. The development of space craft took a focused effort over tens of years, billions of dollars, and vast amounts of creative talent. The development of the computer industry, also involved a huge amount of funding and time.

Breakthroughs in Nanotechnology

Scanning Tunneling Microscope (STM)

Optical or electron microscopes create a magnified image of an object by focusing electro-magnetic radiation, such as photons or electrons, on its surface. Optical and electron microscopes can easily generate two-dimensional magnified images of an object's surface, with a magnification as great as 1000× for an optical microscope, and 100,000× for an electron microscope.

In his 1959 lecture, Feynman wished the electron microscope had been 100 times better. His wish became true 23 years later, after the invention of the STM by Binnig and Rohrer, physicists from the IBM's research labs in Zurich, Switzerland (Binnig *et al.*, 1983). The invention of the STM had enabled the world to see single atoms. With the STM, it is possible to image an object's surface topography with extremely high magnifications, up to 1,000,000×. Further, the magnification of an STM is made in three dimensions.

An STM is provided with an electrically sharp conducting needle/tip, as it shown schematically in Figure 2. The tip is brought up to an electrically-conducting surface, *almost* touching it, to a distance of about 1 nm. The needle and surface are electrically connected, so as the tip approaches the surface, a tunneling current will flow. The needle is delicately maneuvered around over the surface. It has to go up and down as it passes over individual atoms to keep the current constant. The movement of the needle is recorded, resulted in a contour map of the surface of the sample with atomic precision. Because of the sharp increase in tunneling current with decreasing distance, even tips with moderate sharpness yield atomic resolution easily.

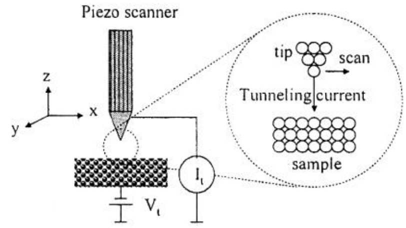

Figure 2. Principles of the STM (Mansoori, 2005)

The STM is a great contribution of Binnig and Rohrer to nanotechnology. They awarded the Noble Prize for this invention in 1986. Scanning tunneling microscopy appeared as a new method to deal with atoms, molecules, and nanometer-scale structures. It can be used for imaging and measuring, which can serve at the same time as tools (Binnig and Rohrer, 1986; Binnig and Rohrer, 1987).

Atomic Force scope (AFM)

Soon after the invention of STM, Binnig developed another microscope which was able to *see* non-conducting surface. In 1985 Binnig, Quate, and Gerber (1986) at Stanford University and IBM San Jose invented the *atomic force microscope* (AFM).